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ABSTRACT

Although progress has been made in combatting the most visible and easily controlled forms of pollution (exhaust, industrial waste, sewage, etc.), other pollutants have been largely ignored. Pollutants which are uncontrolled and which are increasingly recognized as dangerous include carbon dioxide, toxic substances such as dioxin, mirex, lindane, mercuric oxide, lead and mercury, and nuclear wastes. Reasons for lack of success in removing these and other pollutants include the following: (1) pollution control efforts have gone into solving those problems which appeared most solvable, (2) more public expenditures have been aimed at correcting problems which have technical solutions, and (3) some important pollutants cannot be controlled by any known technologies. Analysis of data regarding pollutants indicates that uncontrolled pollution exacts real costs on health and property and that cost-effective investment in abatement equipment can yield measurable net benefits. The conclusion is that controlling pollutants will require fundamental changes in life-styles and common business practices. (Author/DB)

Pollution: The Neglected Dimensions

Denis Hayes

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Table of Contents

Belching smokestacks are much harder to find now than they were a decade ago. However, the pollution problem did not end when it disappeared. Even as progress has been made in combatting the most visible and easily controlled forms of pollution, other pollutants have been largely ignored.

Not surprisingly, the principal pollution-control efforts have gone into solving those problems that appeared most solvable. Public policy and public expenditures have been aimed at correcting problems that have technical solutions. Devices have been attached to automobile exhaust pipes, to industrial chimneys, to sewage pipes—all in an effort to remove certain pollutants from the effluent. The pollutants thus removed have not always been the most dangerous, but they have been the most "removable." For example, the large particles in industrial smoke are now routinely removed, but small particulates —which are more hazardous but more difficult to control—are still emitted in large quantities. The "tonnage" of pollution has thus decreased dramatically, as has its visibility. But much of the danger remains.[1]

Sometimes there is simply no way to control a particular pollutant except by diminishing the volume or intensity of some human activity; there is no technical fix. For example, it is not possible to burn fossil fuel without producing a net increase in atmospheric carbon dioxide (CO_2). If CO_2 is to be controlled, fossil fuel combustion must be reduced. The discharge of chlorofluorocarbon propellants from spray cans can be controlled only by banning the use of such substances, as the United States has now done.

At the heart of the issue is the fundamental physical rule that nothing is ever consumed. Mercury can be mined, transported, processed,

I am indebted to my colleague Christopher Flavin for his help with the research for this paper.

used, and discarded, but as much mercury exists at the end of the process as at the beginning. The metal is simply in a different place, and perhaps in a different condition, than it was before. Pollution is thus sometimes defined as "resources out of place." Most of what passes for pollution control does not recover resources in a useful form; it merely displaces them further. Air pollutants are often converted into water pollutants or into solid wastes. Long-lived radioactive wastes are isolated from this generation but left to haunt our descendants.[2]

Such displacement is generally better than doing nothing, but the net resulting benefits are sometimes small after all costs are considered. For example, scrubbing sulfur dioxide from the effluent of a 1,000-megawatt coal-fired power plant might require a capital investment of $100 million, consume more than 3 percent of the electricity generated by the plant, and produce 40,000 cubic feet of sludge per day. Up to 90 percent of the sulfur dioxide in the stack gases may be removed, but the resulting sludge could eventually become a serious source of water and ground pollution. Microbial action on the sludge might even convert the sulfur into hydrogen sulfide, thus making it again a source of air pollution. A mountain of sludge from powerplant scrubbers may hold marked advantages over an airshed loaded with sulfur dioxide and sulfates. Yet a mountain of sludge hardly constitutes a solution. It merely means that an acute hazard has been traded for a persistent ill.[3]

Such "technical fix" strategies make economic sense in most cases. Uncontrolled pollution can entail substantial costs to human health, physical property, agricultural production, and so forth. These costs are often borne by institutions and people who derive no benefit from the polluting processes. Occasionally, those who pay the price do not even reside in the same nation as those who do the polluting. When polluters are forced to pay for pollution control, the costs borne previously by outsiders are internalized in the production process. The expense of pollution control is then passed on to the consumer in higher prices for products, effectively transferring to the consumer the real costs that were previously experienced by the general public as ill health and property damage.[4]

Unfortunately, many of the costs and benefits of pollution control are difficult to quantify. The effects of pollution on human health and on property are just beginning to be assessed. Only scanty information is available on the impact of pollution upon such natural "free goods" as forests and fish, although it is known that the stunting effects can be very serious. Forest growth in parts of Sweden and California has been reduced by nearly half; game fish have entirely disappeared from many lakes in the Adirondacks.[3]

If little is known about the effects of pollution upon nature's goods, even less is known about its impacts on nature's services. These services—including the degradation of organic waste, the fixation of solar energy, the maintenance of atmospheric gas balances, the cycling of nutrients—are essential to a healthy biosphere. Scientists have just begun to examine the magnitude of these services. For example, they know that every hectare of freeway built through San Bernadino pastureland in California not only will increase the production of carbon monoxide from automobiles but also will reduce the natural carbon-monoxide removal capacity by 440 kilograms per day. In the southeastern United States, a detailed calculation of the value of wetlands as tertiary waste-water-treatment facilities and as fisheries concluded that each hectare cleansed as much water as could be handled by $200,000 worth of modern pollution-control equipment. To the extent that pollution inhibits these natural functions, society suffers a very real loss.[4]

When a pollutant causes obvious harm to humans, the calculation becomes still more difficult. For example, when a pollutant causes premature human deaths, what should the price tag cover—the unrealized earnings of the dead people? Or the costs of hospitalization and health care prior to death? Is a healthy middle-aged executive worth more than an elderly asthmatic on welfare? Should a premium be charged for suffering? For such questions, there are no good answers. Yet decisions must be made. Explicitly or implicitly, regulators have assigned values to the costs of pollution, and have mandated various degrees of pollution control. Only in this way can society determine how much control is enough.

Such an approach holds no promise for pollutants that are not amenable to technical fixes. More surprisingly, it has been rather unsatisfactory for many pollutants that can be controlled with current technology. Time and again, a controllable contaminant of some sort has been found to have an ecological impact that was not anticipated. For the most part, these occurrences can be traced to particular characteristics of the pollutants, that had not been given adequate attention when the pollution-abatement policies were decided upon.

Sometimes there is no mystery about the harmful effects of a pollutant. Exposure to carbon monoxide from an automobile exhaust pipe can cause brain damage and then death within a few minutes. Its toxic qualities are thus rather obvious, and safety standards are comparatively easy to establish. However, this is not always the case with other pollutants. Beryllium poisoning, for example, has been known to occur decades after the victims were exposed to low concentrations of the metal for brief periods of time.[7]

This problem posed by lag times is probably most common with regard to cancer. Many carcinogens take their toll only two or more decades after the time of exposure. It is difficult to predict what the eventual impact on humans will be through tests conducted over briefer periods on other species. Many pollutants are very long-lived, with some posing a danger for hundreds of thousands of years, or even forever. The ill effects to be felt in the distant future are often severely discounted or even ignored by analysts who make decisions with only the short-term outcome in mind.[8]

In assessing the impact of a particular pollutant, analysts tend to ask only, "What damage will this particular unit of pollution do?" But other pollutants in the air and water may have a synergistic or a catalytic effect on the one under consideration. And the current discharge is just part of a constant stream that, over the years, may have a cumulative effect. The amount of acid rain that strikes the Parthenon this year is unlikely to cause unacceptable damage; in the course of decades, however, the structure could be severely defaced. In any one year, the carbon dioxide emitted by fossil fuel consumption will have a negligible effect upon the global climate; once emitted, however, "Many pollutants are very long-lived, with some posing a danger for hundreds of thousands of years."

much of the CO_2 will remain in the atmosphere for a very long time, and after a few decades enough could build up to cause dramatic alterations in the temperature and rainfall patterns of the world.

Finally, some pollutants that are discharged in dilute concentrations into the general environment are reconcentrated by biological activity. Animals that graze large areas, and especially organisms at the lower end of long food chains, can contribute greatly to this biological amplification. A cow, for example, may graze over as much as 1,600 square feet each day. Many trace contaminants can build up in her milk in a relatively concentrated form. Since milk constitutes a large fraction of the diet of infants and children, such a pollution pathway can be particularly pernicious. In some cases, the amount of biological amplification can be quite extraordinary. Clams, oysters, and other mollusks feed by filtering enormous volumes of water, and, while doing this, they separate some trace contaminants out of the water. Some freshwater mollusks can concentrate manganese by a factor of 300,000 and chlorinated hydrocarbon insecticides by up to 70,000 times. While humans could drink the water without suffering ill effects, the poisons concentrated in the flesh of the mollusks can pose real dangers.*

These, then, are some of the neglected dimensions of the pollution problem. They help to explain why, despite the expenditure of hundreds of billions of dollars, some aspects of the environment have persistently deteriorated. The issues are neglected not because people are unaware of them, but because they are so terribly difficult to address.

Yet they must not be forgotten. There is a tendency in public policymaking to analyze in elaborate detail the problems that can be easily solved, and to pretend that the hard problems don't exist. Everything that can be quantified is cranked into the equation; everything else is paid lip service in the preface.

There are several pollutants that are more worrisome today than they were before the birth of the environmental movement. They pose problems that cannot be easily resolved with filters and scrubbers, yet they pose threats too grave to be ignored. All of them have solutions, but such solutions can entail important changes in our lives and in the conduct of our businesses.

Carbon Dioxide

Fossil-fuel combustion always adds carbon dioxide to the atmosphere. A 1,000-megawatt coal-fired power plant emits carbon dioxide at the rate of about 270 kilograms per second, or 16 metric tons a minute. No economically plausible way to capture any significant fraction of this gas has yet been suggested.[10]

Carbon dioxide now constitutes about 330 parts per million (ppm), or 0.03 percent, of the atmosphere. In preindustrial times, the CO_2 concentration was less than 290 ppm, so the level today is about 14 percent over the preindustrial base. By the year 2000, atmospheric carbon dioxide is expected to be 30 percent above the 290 ppm figure; and by 2020, if current trends continue, the preindustrial level will have been doubled.[11]

Such a dramatic increase in global CO_2 will almost certainly result in a significant warming of the earth's atmosphere, with many adverse consequences for life as it now exists. In a comprehensive 1977 study, *Energy and Climate*, the U.S. National Academy of Sciences concluded that climatic considerations might require the phasing out of fossil fuel use within the next 50 years.[11]

While uncertainties remain, these are mostly over matters of scale and rate, rather than direction. The global climate is influenced by solar flux, cloudiness, CO_2, airborne particles, sea and surface temperature, and the reflectivity of the earth's surface (albedo), among other things. Many of these interact in ways that are not entirely understood. Yet at least enough is known about global climatic phenomena to assign ranges of probability to various outcomes. All the most widely accepted models of climatic behavior predict that continued growth in atmospheric CO_2 will increase the planet's surface temperature.

It is sometimes argued that sufficient uncertainty characterizes current knowledge of CO_2 that nothing should be done about the problem for the time being. The National Academy of Sciences report characterizes the potential consequences of such a non-policy in stark terms: "Unfortunately, it will take a millennium for the effects of a century of use of fossil fuels to dissipate. If the decision is postponed until the impact of man-made climate changes has been felt, then, for all practical purposes, the die will already have been cast."[13] 11

This warming phenomenon is generally referred to as the "greenhouse effect." It is easily understood. Each day, the earth receives an enormous amount of energy from the sun. The planet must radiate an equal amount of energy to avoid growing continuously hotter. The wavelength of any radiation depends upon the temperature of the radiating body. The very hot sun gives off radiation of a short wavelength, while the much cooler earth radiates energy at longer wavelengths. Carbon dioxide is transparent to short wavelengths but absorbs certain long wavelengths, including those given off by the earth, thus trapping the heat. The CO_2 gas is itself warmed up by the absorbed energy, and reradiates part of it back to earth. This increases the overall temperature of the earth's atmosphere. It is believed that the earth would be about 10° C cooler if there were no CO_2 in the atmosphere.[14]

A doubling of atmospheric CO_2, according to the National Academy and other studies, could lead to an increase in average global temperature of between 1.5° and 3° C. At first glance, this would seem a rather insignificant change. However, this "average" shift in global temperature would not be uniformly distributed over all regions. In polar regions, for example, the impact would be several times greater than the global average. A look at the world's climatic history places a 3° C shift in better perspective. Between the peak of the last glacial period (20,000 to 16,000 years ago) and the peak of the current, warmer "interglacial" period, the mean temperature of the ocean rose 2° C and the mean global temperature warmed 5° C. During the last glacial period, the sea level was more than 100 meters lower than it is now. The wide continental shelf that borders the east coast of North America was dry land. When the glacial ice melted, the sea rose. Had cities been built in what were then coastal areas, they would now be submerged. If rising global temperatures in the years ahead cause widespread melting of polar ice, the world's oceans will rise still further, affecting current coastal cities.[15]

Professor J. H. Mercer, in an article published in the British scientific journal *Nature*, contends that major sea-level displacements may be unavoidable. A single doubling of atmospheric CO_2 could, he believes, result in a rapid deglaciation of West Antarctica. This, in turn, would lead to a five-meter rise in sea level, covering many low-lying land areas, including much of Florida, the Netherlands, and the principal rice-growing river deltas of Asia. Although the change in the sea level would probably not be uniform all over the world, an average increase of five meters would most likely inundate the major coastal cities and would reduce the earth's land surface at a time when population pressures are calling for more land—not less.[16]

Before the world's oceans rise dramatically, an increase in world temperature would affect global food production. Rainfall patterns could shift, regional temperatures could soar, and the world's delicately balanced agricultural system would undergo considerable change. Some land might have to be abandoned, while other land—of unknown quality—would have to be reclaimed. Existing irrigation and drainage systems that cost billions of dollars would have to be changed to reflect new rainfall patterns. In Asia, where over half the world's people live, terraced irrigation systems represent the investment of centuries of human labor. As different crops might be grown in some areas, different infrastructures would be needed to process and market them.[17]

The net global effect is impossible to predict. Some regions would clearly suffer adverse effects; others might find their lot improved. But the process of change itself would be tortuous and costly in terms of human life. The existing agricultural system has very little slack capacity, and it is closely fitted to the climate that has prevailed for the last several thousand years. Any alteration in climate would be disruptive; large climatic changes could be catastrophic.

> **"A single doubling of atmospheric CO_2 could result in a rapid deglaciation of West Antarctica."**

Historically, shifts from glacial to interglacial periods have occurred over thousands of years. The world is now faced with a doubling of atmospheric CO_2, with its possible attendant climatic shifts, in roughly 50 years. And that, theoretically, could be just the beginning. Although the combustion of the world's proven oil and gas reserves would not be likely to cause unacceptable climate changes, coal-burning poses a greater threat. If the entire global coal reserve were to be burned, atmospheric CO_2 could increase eightfold. Burning the world's shale oil supply could result in a still greater increase.

In fact, however, it would be wise to avoid even one doubling. The atmosphere already contains more CO_2 than has ever prevailed since the evolution of *Homo sapiens*. If it is arbitrarily assumed that cumulative atmospheric carbon dioxide from human sources should not add more than 50 percent to the preindustrial level of CO_2, then modest growth in the use of fossil fuels could continue only through the end of this century, after which fossil fuel combustion must decline rather sharply. Moreover, because of the rather long lead times needed to convert from one energy source to another, a decision to reduce fossil fuel use swiftly after the year 2000 would have to be made no later than 1980—an unlikely prospect.

Toxic Substances

In the past, the dangerous by-products of manufacturing have been buried on land or at sea, or released at concentrations so dilute that they appeared to pose no hazard. That legacy has in recent years come to haunt us.

In the community of Love Canal, New York, for example, 200 homes were boarded up in 1978 and the school was closed when an unusual number of birth defects and persistent illnesses were discovered in the area. During the forties, the Hooker Chemical Company had dumped tens of thousands of tons of toxic materials, including mirex, lindane, and dioxin, at various sites near the town. For three decades, people built houses, worked, and played in the area, but today a deadly cocktail of chemicals is seeping toward the surface at 15 dumps in that one New York county alone. Similar problems are erupting at other sites around the world.[18]

In late November 1978, U.S. Environmental Protection Agency (EPA) Administrator Douglas Costle announced that there are about 32,000 potentially dangerous chemical dumps throughout the United States. Of these, 638 are thought to possibly pose "significant imminent hazard to human health." Costle estimated that 80 to 90 percent of the hazardous wastes currently being generated are not being disposed of in ways that will meet forthcoming health and safety standards.[19]

In a sense, the most persistent pollutants are metals. Nuclear proponents are fond of joking that whereas plutonium will cease to pose an important problem in 250,000 years or so, lead and mercury and arsenic will be around forever. And, indeed, some metals can pose a formidable permanent hazard.

To be sure, metals are widely distributed in the environment; consumed in minute quantities, they are frequently essential to plant and animal health. Some metals, however, when concentrated above natural levels constitute a serious threat if inhaled or ingested. Heavy metals, such as mercury, lead, cadmium, chromium, and nickel, have received considerable attention, but other metals can also pose risks.

Fifty years ago, arsenic was the only metal known to be a carcinogen. Today, it has been established that cancer can be caused by beryllium, cadmium, chromium, cobalt, iron, lead, nickel, selenium, titanium, and zinc. As a category of pollutant, the heavy metals are rather comprehensive in their potential attacks on the human body. For example, certain forms of mercury and lead attack the central nervous system; nickel and beryllium, the lungs; cadmium, the kidneys; and antimony, the heart.[20]

Unlike radioactive wastes, toxic metals have no half-life. Like carbon dioxide, they are removed only through slow processes that operate over geologic time. As wastes, they cease being troublesome only when they are buried so deep in sediment that they are unlikely to be disturbed. The most successful control strategy, of course, would be to keep the metals in circulation as useful products rather than discharging them into the general environment.

Environmental mercury has several anthropogenic sources. It is released in the combustion of fuels and the high-temperature processing of some minerals; it is a by-product of various manufacturing processes; it is distributed widely in biocides; and it can be released directly from discarded consumer products. Fuel combustion and mineral processing contribute an estimated 350 tons of mercury to the air each year in the United States alone, but it is often at concentrations of less than one part per million in combustion gases. Technology to control it is thus difficult to design.[21]

Mercury is used in a wide variety of manufacturing processes, from the production of electrical equipment to dental supplies. Worldwide mercury production is about 9,000 tons per year. In 1976, less than 10 percent of this mercury was recycled; in the United States, the EPA estimates that more than 70 percent of the mercury used each year escapes into the environment.[22]

In Minamata, Japan, which has come to symbolize the pollution problem to many people, a chemical plant started using mercuric oxide as a catalyst during the forties, dumping large quantities of mercury waste into the local bay. Marine organisms converted this mercury into methyl mercuric chloride, which worked its way into the fish in the bay, and then into the local diet. An unexplained neurological disorder was found in the area in 1953, and by 1956 this affliction had reached epidemic proportions. In 1959, Dr. Hajime Hoskowa, a chemist with the offending company, determined that the plant's mercury was the cause of the disease, but the firm did not reveal this evidence for a decade. The mercury dumping continued until 1971. Now more than 1,000 victims have been certified, and the total may eventually include another several thousand.[23]

Mercury is also used in many biocides, and is thus distributed widely in the environment. Occasionally, human error can lead to catastrophe. In 1972, a large quantity of seed grain that had been intended for planting and had been treated with a methyl mercury fungicide was distributed to Iraqi villagers. Some fed it to farm animals, and others used it in bread. The toll was staggering: 459 people died and thousands suffered a variety of afflictions.[24]

Another heavy metal whose dangers have been remarked upon since the days of the Roman Empire is lead. It has long been recognized that large quantities of lead, especially if ingested, can lead to major disorders and even death. More recent evidence shows that very low concentrations of lead, particularly in children, can adversely affect enzymes, various organs, and especially the nervous system. Now that lead has been eliminated from paints in many countries, the greatest problem is that posed by atmospheric lead. In industrial countries, the main source is the use of leaded gasoline in automobiles. In the United States, for example, more than 98 percent of the atmospheric lead comes from the combustion of leaded gasoline. A typical car emits from 2 to 4 pounds per year, and the country has roughly 100 million cars. As alternative modes of transportation become popular, this source of lead pollution should diminish dramatically. In addition, during the transitional period when gasoline is likely to be mixed with increasing percentages of ethyl alcohol and marketed as "gasohol," the situation will improve. Ethyl alcohol performs much the same octane-boosting function as tetraethyl lead.[25]

Arsenic is widely appreciated as a poison when administered in concentrated doses. But it also poses risks when emitted in dilute streams of pollution. The Anaconda Company once captured much of the arsenic in the smoke from its huge copper smelter in Anaconda, Montana. But in 1971 the market for this by-product disappeared. Over the next five years the company poured about 12 tons of arsenic a day out of the world's tallest smokestack—a 585-foot spire visible 20 miles away. In 1975, the surrounding county was found to rank ninth in lung cancer rates in a nationwide survey by the National Cancer Institute—a condition that doubtless reflected long exposure to the pre-1971 levels. The rate may rise even further when sufficient time has elapsed for the emissions of the seventies to have an impact. The company has since dramatically cleaned up its emissions; without a market for the arsenic, however, the captured toxic metal is now being buried.[26]

Perhaps the most serious problem connected with the control of heavy-metal emissions stems from the fact that they commonly enter the air as tiny particles. Particulates in the submicron range are not affected by most air pollution control technologies. Once emitted, they are barely affected by gravity, but are eventually removed from the atmosphere by rain. It has been found that heavy metals constitute a disproportionate percentage of the small particulates emitted by coal-fired power plants. In effect, the most dangerous trace elements in the coal condense preferentially onto particles too small to be effectively controlled by current technology and against which the human respiratory system has the poorest defenses. Again, it is a problem that currently has no solution except in the reduction of certain human activities.[27]

The problems posed by toxic metals are serious. The benefits derived from their use are similarly great. The task today lies less in designing new pollution-control technologies than in constructing an economy in which these valuable materials are not thrown away to wreak havoc. If products were designed to be reused and recycled instead of thrown away, less metal would be used overall, and less of what was used would be released into the environment.

A variety of nonmetallic toxic substances can also pose serious problems. Of particular concern are those having a tendency to become concentrated through the food chain. One of the best known instances of biological amplification occurs with the insecticide DDT. When DDT is sprayed on an area, it remains potent for a long period. During this time, because it is readily absorbed by living organisms it can work its way up the food chain. When ingested by an animal, it tends to accumulate in the fatty tissue instead of being excreted. When one fish eats another, most of the meal is digested and then excreted, but much of the DDT is retained. As small fish are eaten by larger ones, which in turn are finally eaten by birds, the ratio of DDT to body weight increases steadily at each stage.[28]

At high concentrations, the chemical impairs reproductive functions in birds, causes liver damage, and results in neurological disorders. Dramatic reductions in certain bird populations during the fifties and sixties were attributed to DDT, and the fact that it accumulates in the fatty tissue of human beings became a cause of increasing concern. In 1962, Rachel Carson provided a critical examination of the ecological effects of DDT in her book *Silent Spring*. Its examination of ecological interdependencies provided one of the earliest exposures of the public to such thinking.[29]

Polychlorinated biphenyls (PCBs) are a family of chemicals that have long been known to be dangerous, and they are thus introduced into the environment only in very dilute forms. More than 200 types of PCBs have been manufactured. Different kinds have different properties, and are used in products ranging from electrical insulators and plastics to pesticides and hydraulic fluids. It is not clear which PCBs pose serious dangers to humans or at what levels these dangers become acute. In 1968, some Japanese rice oil was contaminated by PCBs that accidentally leaked from a heating system. People who ate the rice oil suffered skin ailments, liver damage, swollen arms and legs, and other symptoms. About 1,200 cases of PCB poisoning were reported. At about the same time that this PCB-caused disease appeared in Japan, worldwide testing for DDT unexpectedly disclosed concentrations of PCBs in many places, particularly in marine life. Because PCBs are very stable compounds that accumulate in the fatty tissues of organisms, they are capable of extreme bioamplification. By the time they work their way up from microscopic creatures to large birds and carnivorous sea mammals, with a ten to 100-fold magnification at each step, they can be concentrated ten million-fold over their levels in the surrounding water. In recent years, strict standards for allowable PCB levels in fish have been set by several countries, and some areas have banned fishing in highly contaminated waters.[30]

It is a cruel irony that large expenditures on water pollution control were made before PCB contamination was known to constitute a real hazard: expensive facilities were built that were unable to remove PCBs from the sewage discharge. When commercial fishing was banned in the Hudson River in late 1975 because of PCB fears, more than $3 billion had already been spent on sewage treatment plants that were not designed to remove these materials. Similar problems

"A simple evaluation of the toxicity of a dilute pollutant is an inadequate measure of its environmental impact."

have surrounded the discharge of other chlorinated organic compounds, including kepone and mirex, that have recently been found to be hazardous.[31]

The routes that various contaminants follow through the living environment are not well-understood. When DDT was first used to kill harmful or annoying insects, no one could have predicted that it would eventually threaten the existence of whole species of birds. It has become clear that a simple evaluation of the toxicity of a dilute pollutant in the air or water is an inadequate measure of its environmental impact. Serious attention must also be paid to the pathways the pollutant will follow through various chains of life, and of the potential for significant increases in its concentration through biological amplification.

The modern international industrial market allows a new material to be invented, manufactured, and sold in large quantities around the world in a matter of years. In earlier eras, fewer products were introduced each year, production volume grew relatively slowly, and the products were first used in limited regions—generally near the point of manufacture. Hence, the chances were greater that if a new material was harmful, the threat might be detected before a worldwide market developed. Today's world is more dangerous.

Nuclear Wastes

Every light bulb lit by nuclear power bears a cost that does not show up on the consumer's utility bill: a dangerous by-product that will need to be guarded for thousands of years. No country has yet found a permanent solution to the problem posed by nuclear wastes. Indeed, much of the mounting international wariness about nuclear energy derives from a growing public recognition that, after a quarter-century of nuclear power, the waste issue remains unresolved.

Spent fuel is the most hazardous type of nuclear waste. As a reactor operates, fissile atoms are split, yielding smaller atoms known as fission products. After about three years, enough fission products have accumulated in a conventional light-water reactor that the fuel must be changed. At this point, the fuel rods are removed from the reactor and stored nearby under water until their most intense radioactivity cools somewhat. Then they are either disposed of intact or they are taken to a reprocessing plant where fissile isotopes are removed for recycling.[32]

The most controversial element in spent fuel is plutonium. It is toxic, carcinogenic, easily separated from the rest of the fuel by chemical means, and capable of being used to fuel reactors or to build atom bombs. A 1,000-megawatt reactor typically produces about 375 kilograms of plutonium per year of operation. The official position of the United States is that this plutonium should be left in the spent reactor fuel and disposed of as radioactive waste, rather than reprocessed for use as fuel. Plutonium, however, has a half-life of about 25,000 years, while the most immediately dangerous elements that would cohabit a waste repository lose most of their potency in a matter of centuries. Thus if plutonium is buried with wastes, these nuclear dumps could eventually become plutonium *mines*. On the other hand, if the plutonium is recycled as fuel, the problems that would be posed by "plutonium mines" some centuries hence become instead an immediate threat as this exceedingly dangerous material is shipped around the world and bought and sold as a common item of commerce.[33]

Before nuclear power comes to play a significant role in the world energy picture, a decision must be made either to face up to the plutonium problem today or to bequeath it to the future. Since the problem will remain serious through at least ten half-lives, one-quarter of a million years, the wastes cannot simply be buried and forgotten.

Most of the wastes generated thus far by nuclear power plants are in temporary storage until a decision is reached about a safe way to store them permanently. Nonetheless, some experience in the storage of high-level wastes has been provided by the U.S. nuclear weapons program. The story is not one to inspire confidence. Over 70 million gallons of this dangerous liquid are stored at the Hanford facility in

"Nearly 500,000 gallons of high-level nuclear wastes have leaked from tanks at Hanford and Savannah River."

Washington and the Savannah River facility in South Carolina. There have been 20 major leaks at Hanford since 1958. The largest, in the spring of 1973, saw 115,000 gallons of high-level wastes escape into the soil. In all, nearly 500,000 gallons of high-level nuclear wastes have leaked from tanks at Hanford and Savannah River.[34]

In addition to high-level wastes, nuclear power also produces a large volume of low-level wastes. While these are neither as dangerous nor as difficult to store as high-level wastes, they can pose problems if not handled with a clear understanding of the long-term commitment required. Tens of thousands of large steel drums containing low-level nuclear wastes from Europe and America were dumped at sea before this practice was recognized as dangerous. Many of these containers have not withstood the rigors of even a couple of decades.[35]

A third type of nuclear waste is that of worn-out nuclear facilities, especially power plants and reprocessing plants. Subjected to intense neutron bombardment, the materials in such units become radioactive during the structure's operating life. When the plant has outlived its usefulness, the security of its radioactive components must be guaranteed. While cost estimates vary, depending upon the level of protection that is sought and the urgency with which it is desired, the upper end of the range is intimidating. Estimates of the cost of decommissioning a nuclear fuel reprocessing plant at West Valley, New York, run over $1 billion. If this charge were to be placed on the utility bills of those customers who benefited from the plant during its brief period of successful use—an option not under serious consideration by anyone in authority—the result would most likely be a political rebellion.[36]

This political aspect of the nuclear-wastes issue is becoming as important a consideration as the technical problems of disposal. Large numbers of people in many societies don't trust their governments to handle such materials, and they trust private industry even less. In November 1978, the citizens of Austria voted against opening the already-completed $600 million Zwentendorf nuclear power plant, despite an impassioned campaign on behalf of the plant by the Prime

Minister. Waste disposal was the most prominent issue in the referendum. Nuclear waste is similarly a hot political issue in England, Sweden, and most communities located near a proposed nuclear dumping site.

In some large measure, the technical debate over the relative merits and disadvantages of salt beds, granite, clay, and other media for waste storage is being displaced by a general concern over proximity. People who live near salt formations don't want nuclear wastes placed in salt, while people who live near suitable granite formations are well-informed about the problems associated with disposal in granite, and so forth. In the United States, a growing number of states are concerned about the rising inventories of spent fuel being stored temporarily on reactor sites and are prohibiting new nuclear construction until a strategy for permanent waste storage is adopted. At the same time, a great many states have expressed grave reservations about hosting a nuclear-wastes repository, or even letting spent fuel travel across the state en route to a permanent repository elsewhere. It may well be that these inner limits imposed by social and political factors will prove more of a constraint on nuclear development than the very real technical uncertainties surrounding waste storage.[37]

Ultimately, there is no technical fix for the problems presented by nuclear wastes. Greater degrees of safety can always be provided at greater costs, but absolute and timeless safety can never be assured. While some of the wastes—notably fissionable isotopes of plutonium and uranium—can be recycled, most radioactive wastes can only be isolated from human society in some sort of repository. And the recycling of plutonium and fissile uranium poses more formidable danger than does disposal of these substances with the wastes.

If the benefits of nuclear power are to be enjoyed today, it should be with the understanding that some of the hidden costs will be passed on to our children and grandchildren. And to their children and grandchildren. The growing resistance to nuclear power represents one of the first times that a large part of the population has developed an understanding of an issue of fairness to future generations. Many people seem willing to forgo some current consumption in order to avoid placing a burden on their descendants.

Conclusions

Over the past decade, most of the industrial world and much of the developing world has grown comfortable with the concept of pollution control. It is widely recognized that uncontrolled pollution exacts real costs on health and property and that cost-effective investments in abatement equipment can yield measurable net benefits. However, some important pollutants cannot be controlled by any known technologies. Checking these will require fundamental changes in life-styles and common business practices. It is far more difficult to achieve such changes than it is to mandate filters for smokestacks. As a consequence, there are few success stories in this realm. 23

One of the very few examples of an adjustment in the economic system to avoid the consequences of an unsolvable pollution problem involves chlorofluorocarbons. These compounds are chemically inert, have low toxicity, and have long been used as the working fluid in refrigerators and air conditioners. In recent years, they have been employed widely as a propellant in aerosol cans containing deodorants, hair sprays, insecticides, and other substances. An estimated three billion aerosol cans using 1.7 million pounds of chlorofluorocarbon were sold in 1973.[38]

It is generally believed that chlorofluorocarbons rise gradually to the stratosphere. There, they react chemically with the ozone, thereby reducing the concentration of this protective layer of gas and allowing more harmful ultraviolet rays to strike the earth. For humans, this translates into a sharp rise in the incidence of skin cancers. The effects are cumulative, and the longer the chlorofluorocarbon emissions continue, the greater the total impact will be. In 1977, the U.S. Environmental Protection Agency banned the use of these compounds for many purposes. However, the integrity of the ozone layer is an international problem, and no mechanism other than persuasion exists to create a similar ban throughout the world.

The response time, at least in the United States (which produced and used most of the world's spray cans), was remarkably quick on this issue. The reduction of stratospheric ozone by chlorofluorocarbons was not discussed in the scientific literature until 1974, and by 1977 concrete action had been taken. However, the level of sacrifice needed was modest as other aerosol propellants were available, and the potential benefits were very great. It remains to be seen how many other cumulative impacts of our global chemical experimentation are discovered, and what the response will be when more impressive levels of sacrifice are demanded.

The types of pollution surveyed in this paper—CO_2 buildup, toxic substances, and nuclear waste—pose formidable challenges. But they are less a challenge to the scientific and engineering skills of technological problem-solvers than a challenge to our social values and institutions, our capacity to forswear a course of development that provides clear benefits in the short run but unacceptable costs in the future.

The choice—curbing fossil fuel use or facing inevitable climate changes—is best made from a social perspective, with an awareness that the issue cuts across generations and national borders. The generation making the critical decisions on CO_2 will not have to live with the long-term consequences of their policies. Enlightened policies can be successfully pursued only through cooperative international efforts, involving especially the United States, the Soviet Union, and China.

The United States is by far the largest producer of CO_2, yet its net contribution in the year 2000 is not likely to exceed 20 percent of the world total. Even if the United States were to unilaterally wean itself from fossil fuels over the next two decades, four-fifths of global CO_2 production would continue. The Soviet Union contains 56 percent of the world's known coal, and China holds another 8 percent. Burning this coal would yield energy benefits and failing to burn it would involve significant sacrifices for both countries. Yet if even one-tenth of this fuel were burned, the global consequences would probably be large, adverse, and essentially irreversible.[39]

If the world is to avoid turning into a "greenhouse," large investments must soon be made to increase energy efficiency and to de-

"Even if the United States were to wean itself from fossil fuels over the next two decades, four-fifths of global CO_2 production would continue."

velop renewable energy resources. In particular, it is important that biological energy sources be rapidly brought into a state of equilibrium—so that new crops take enough CO_2 out of the atmosphere each year to balance the CO_2 emitted during the combustion of other crops. An aggressive energy conservation and solar program will require far greater effort than currently envisaged even in those countries that are now pursuing such a path.

Just as it is impossible to burn coal without producing carbon dioxide, it is impossible to run a nuclear reactor without producing radioactive wastes. Currently a major international controversy is raging around the emotionally charged issue of waste disposal. Within the technical community, the debate concerns such issues as the best technology for solidifying the waste, the best medium for long-term storage, and the benefits and risks of recycling plutonium. However, much of the general public is uninterested in the subtleties of the issue. They know only that a dangerous brew is being concocted that must be contained safely for thousands of years, and they have little faith that existing social institutions are equal to the task.

The general public may be closer to the heart of the issue than are the experts. The technological elements of the debate are easier to address, but probably less important, than the social dimensions. The crucial question involves the likelihood of a high degree of international social and political stability for many thousands of years. Unless people are willing to pay the price that such stability implies—probably an unprecedented degree of international authoritarian control—nuclear wastes pose a threat that for all practical purposes is without end.

The broad category of "toxic substances" encompasses a wide variety of materials. Most of them serve useful purposes, but if misused, they pose a danger. Lead in a lead-acid battery can help store electricity, but if ingested it can cause brain damage. The objective with toxic substances is to apply them to constructive purposes without spewing them into the general environment. This can be achieved in part through regulatory processes such as those mandated by the U.S. Toxic Substances Control Act. Sometimes compliance with these regulatory requirements will be sufficiently costly for whole new approaches to the problem to suddenly become practical. The cost of containing the toxic substances in wastes, for example, could make it more attractive to reduce the size of these waste streams by separating and recycling more of these substances back into productive uses.

Consider the coal-fired power plants in the United States that now produce about 60 million tons of solid waste each year as products of air pollution control. This material is currently disposed of in pits, ponds, and landfills for about $2 a ton. About 13 percent of all fly ash captured during the burning of the coal is used directly in civil engineering projects—mostly road building. These wastes contain a broad assortment of heavy metals, sulfates, and carcinogenic hydrocarbons. If this material is classified as hazardous waste by the EPA, as now seems quite possible, the cost of disposal will soar to about $90 a ton, and direct use in road building will be prohibited. The cost of disposal would then nearly equal the cost of the fuel. Even if the wastes are not deemed hazardous, the cost of disposal is expected to rise to about $10 per ton just to meet current disposal standards.[40]

Today, because disposal costs are not high, utilities tend to buy "throwaway" scrubber systems that produce lots of sludge. If sludge disposal gets very expensive, however, utilities are likely to purchase more costly regenerative scrubbers that produce elemental sulfur or sulfuric acid. And if the cost of waste disposal goes to $90 a ton, it will become attractive for the utility to "mine" the sludge and other solid-waste residues to recover potentially valuable materials that would otherwise be potentially dangerous contaminants. In Japan, a law entitled the "Compensation of Pollution-Related Health Damage" internalizes the costs of pollution through emission charges levied on polluters. Tens of thousands of people are compensated from these funds each year for pollution-induced illnesses. If the concept could be broadened to encompass the costs of all environmental damage and was applied internationally, the effects could be dramatic.[41]

Many of these new pollution issues gain a compelling importance only when they are considered over the long term. The world will be little affected by the CO_2 from next year's fossil fuel combustion, except as it is part of a cumulative total that spans several decades. The problem is important, but it is difficult to persuade people that it is urgent. Most policymakers are forced by circumstances into shortsightedness. Corporate managers are governed by annual profit-and-loss statements; politicians have a time horizon that extends to the eve of the next election.

Indeed, much of the economic literature that dominates policy analysis so emphasizes present value and discounts future costs that it becomes difficult to pay serious attention to the long-term ill effects of today's decisions. Yet unless attention is paid to all the damage pollutants can cause over their lifetimes, current investments in pollution control are likely to be inadequate. Sometimes disasters create the necessary public awareness. The mercury poisoning of more than 1,000 people in Minamata, Japan, created a widespread awareness of the heavy-metal problem. The forced evacuation of 200 families from Love Canal, New York, promises to bring similar attention to the issue of dumps of hazardous materials.[42]

It seems cruel, however, to depend upon tragedies to prompt progress. Sometimes other events can be organized to achieve the same broad educational objectives. Much of the initial attention that doomed the American SST aircraft was generated by Earth Day, a nationwide environmental day of concern in 1970. Other issues, ranging from war to civil rights to farm policy, have been catapulted to prominence by organized events. United Nations conferences can sometimes focus international attention on global issues. A U.N. conference on the carbon dioxide problem might begin a process that would boost the priority given this issue in many lands.

Long-term, invisible pollutants are difficult to focus attention upon, but it can be done. Life-style changes and major shifts in industrial processes are difficult to promote, but nonetheless they can occur. When pollutant effects are cumulative, time is of the essence. Delay may lead to irreversible damage. Sooner or later, the neglected dimensions of the pollution problem will have to be addressed.

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